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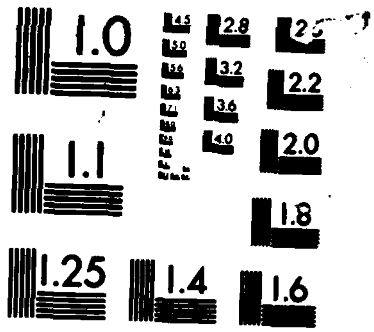

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DYNAMIC FRACTURE AND DEFORMATION OF SOLID PROPELLANT

FINAL TECHNICAL REPORT

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J.R. WALTON

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Contributions to the topics of high speed crack growth in linear viscoelastic media and nonlinear viscoelastic constitutive equations are summarized. Reports and publications covering this work are listed.

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SUMMARY OF WORK ACCOMPLISHED

Contributions to two distinct but related topics have been made: (1) high speed crack growth in linear viscoelastic media and (2) nonlinear viscoelastic constitutive equations for particle-filled rubber with microcracks. Both are relevant to the dynamic mechanical response of solid propellant.

(1) High speed crack growth: Work was completed and published [1] on the dynamic steady-state propagation of an antiplane shear crack in a general linear viscoelastic layer. An infinite series representation for the stress intensity factor was derived, each term of which can be calculated recursively in closed-form. A simple, universal dependence upon crack speed and basic material properties was found. These results represent a significant step in understanding the influence of a physical dimension (the layer thickness) on dynamic stresses in the neighborhood of crack tips in rate-dependent materials.

Another paper [2] is partly a summary of principal results in [1] and [3] and contains new material not published elsewhere. Specifically, the analysis of [3] was extended to derive the full stress field in the body. A much simpler form than was presented in [3] for the entire stress field ahead of and in the plane of the crack was exhibited and the angular dependence of the local stress field at the crack tip was calculated. The usual asymptotic methods of an elastic analysis (involving scaling the governing differential equations) could not be applied to the viscoelastic problem due to the presence of convolution integrals. Rather, the asymptotic stress field at the crack tip was derived in local polar coordinates by doing a direct asymptotic expansion of the general

representation for the full field. By this method it was shown that the angular dependence of this dynamic viscoelastic problem is the same as for the corresponding dynamic elastic problem; only the stress intensity factors differ.

The steady-state propagation of a semi-infinite, antiplane shear crack was reconsidered in [4] for a general, infinite, homogeneous and isotropic linearly viscoelastic body. As with an earlier study, the inertial term in the equation of motion was retained and the shear modulus was only assumed to be positive, continuous, decreasing and convex. A Barenblatt type failure zone was introduced in order to cancel the singular stress, and a numerically convenient expansion for the dynamic Energy Release Rate (ERR) was derived for a rather general class of crack face loadings. The ERR was shown to have a complicated dependence on crack speed and material properties with significant qualitative differences between viscoelastic and elastic material. The results were illustrated with numerical calculations for both power-law material and a standard linear solid.

An analysis was presented in [5] of the steady-state propagation of a semi-infinite mode I crack for an infinite inhomogeneous, linearly viscoelastic body. The shear modulus was assumed to have a power-law dependence on depth from the plane of the crack. Moreover, both a general and a power-law behavior in time for the shear modulus were considered. A simple closed form expression for the normal component of stress in front of the propagating crack was derived which exhibits explicitly the form of the stress singularity and its material dependency. The crack profile was examined and its dependence on the spatial and time behavior of the shear modulus was determined.

(2) Nonlinear viscoelastic constitutive equations: In [6] a model based on micromechanics for predicting effective viscoelastic stress-strain equations and microcrack growth in particle-reinforced rubber (or other relatively soft viscoelastic matrix) was described. Geometric idealization of the microstructure followed that of the composite spheres assemblage and generalized self-consistent scheme originally used for linear elastic composites without damage. The approach combined a perturbation analysis of the matrix, which becomes more accurate as the particle volume fraction is increased, with the Rayleigh-Ritz energy method for predicting mechanical response of the composite. Results for linear elastic behavior with crack growth were first obtained, and then extensions to linear and nonlinear viscoelastic behavior were given. It was shown that the elasticity theory may be easily extended to predict mechanical response of a viscoelastic composite, and that an approximate equation governing microcrack growth is analogous to one for an aging elastic material. Finally, a limited assessment of the theory was made through comparison with some existing theoretical effective modulus results and experimental data on solid propellant.

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[3] J.R. Walton, "On the Steady-State Propagation of an Anti-Plane Shear Crack in an Infinite General Linearly Viscoelastic Body," Quart. Appl. Math., 37-52 (1982).

[4] J.R. Walton, "The Dynamic Energy Release Rate for a Steadily Propagating Anti-Plane Shear Crack in a Linearly Viscoelastic Body," Texas A&M Univ. Report MM 4867-86-3 (January 1986). Submitted for publication.

[5] L. Schovanec and J.R. Walton, "The Quasi-Static Propagation of a Plane Strain Crack in a Power-Law Inhomogeneous Linearly Viscoelastic Body," Texas A&M Univ. Report MM 4867-86-4 (January 1986). Submitted for publication.

[6] R.A. Schapery, "A Micromechanics Model for Nonlinear Viscoelastic Behavior of Particle-Reinforced Rubber with Distributed Damage," Texas A&M Univ. Report MM 4867-86-1 (January 1986). Submitted for publication.

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